SEGMENTED COIL FOR GENERATING PLASMA IN PLASMA PROCESSING EQUIPMENT

BACKGROUND OF THE INVENTION

The present invention relates generally to a segmented coil for a transformer coupled plasma (TCP) source. More specifically, the present invention relates to a segmented coil configuration as a source for generating a plasma which can be used for treating semiconductor wafers in low pressure processing equipment.

Plasma generation is useful in a variety of semiconductor fabrication processes, for example enhanced etching, deposition, etc. Plasmas are generally produced from a low pressure gas by inducing an electron flow which ionizes individual gas molecules through the transfer of kinetic energy through individual electron-gas molecule collisions. The electrons are commonly accelerated in an electric field, typically a radio frequency (RF) electric field.

Numerous techniques have been proposed to accelerate the electrons in an RF electric field. For example, U.S. Pat. No. 4,948,458 discloses a plasma generating device in which electrons are excited in an RF field within a chamber using a single winding coil (SWC) that is parallel to the plane of a semiconductor wafer and the plasma. As shown in FIG. 1, a typical plasma generating device includes RF circuitry comprising an RF source **30** coupled via a coaxial cable **32** through an impedance matching circuit to an SWC **20**. The impedance matching circuitry includes a loop **34** and a coil **36**. A tuning capacitor **38** is also provided as part of the RF circuitry to adjust the circuit resonant frequency to the RF driving frequency. A process gas is introduced into a chamber **10**, and an RF current produced by the RF source **30** is resonated through the SWC **20**, causing a planar magnetic field. The magnetic field causes a circulating flow of electrons between the coil **20** and the wafer W which is supported by a surface **40**, generating a plasma in the chamber **10**.

A typical SWC is shown in detail FIG. 2. The SWC **20** comprises a singular conductive element formed into a planar spiral or a series of connected concentric rings. The SWC **20** includes an inner tap, i.e. terminal, labeled (+) and an outer tap, i.e. terminal, labeled (−) so that it can be connected to the RF circuitry. Hence, coil **20** includes an inner terminal, an outer terminal and an arcuate conductor portion having at least one turn connected between the inner and outer terminals.

When processing semiconductor wafers in plasma gas environments, it is desirable to uniformly process the entire surface of the wafer. The single winding monolithic coil, such as that described, above does not provide the same uniformity at all operating pressures. For example, at one pressure the center of the wafer may be etched at a higher rate than remaining portions of the wafer while at another pressure the center of the wafer may be etched at a lower rate than remaining portions of the wafer. Other process parameters, such as RF power, gas species and flows, may also affect the rate at which the center is etched.

Several methods have been proposed to optimize plasma uniformity. For example, U.S. Pat. No. 4,615,755 discloses a plasma etching technique wherein uniformity of the wafer temperature is achieved by He backcooling of a wafer supported on a bowed electrode. By bowing the wafer away from the lower electrode with the cooling helium, cooling performance of the wafer is sacrificed in order to achieve

etch uniformity. However, variations in the thickness of the wafer result in sub-standard control of the wafer bowing, thereby reducing the etch uniformity.

Another proposed solution for optimizing plasma uniformity is to adjust the process parameters. A problem with this proposed solution is that once process parameters are adjusted to obtain uniformity, only a small parameter range is typically available for optimizing other etch responses, such as profile.

Yet another proposed solution for optimizing plasma uniformity is to modify the reactor configuration by shaping the plasma window or by adding shrouds, spacers, or focus rings. The disadvantage of this approach is that such modifications are fixed and work best in a limited parameter range.

There is thus a need for a plasma generating coil that optimizes plasma uniformity but does not limit the parameter ranges needed for optimizing other etch responses.

SUMMARY OF THE INVENTION

The invention provides an apparatus for generating a transformer coupled plasma (TCP), the apparatus comprising a plasma reaction chamber into which a process gas is introduced, a coil comprising at least a first coil segment and a second coil segment connected in series and disposed proximate the chamber, and a radio frequency source coupled via RF circuitry to the segmented coil. The radio frequency source resonates a radio frequency current in the segmented coil and excites the process gas into a plasma within the chamber. Variable electrical components are connected across or between the first and second coils to selectively change the RF current in each segment coil relative to the other segments. The variable electrical components permit the segment coil currents to be adjusted to improve the spatial uniformity of RF power coupling in the plasma, thereby improving the plasma and process uniformity such as etching, deposition, etc., in the reaction chamber.

Preferably, each of the coil segments has an inner terminal, an outer terminal and an arcuate conductor portion having at least one turn extending between the inner and outer terminals.

According to various aspects of the invention, the variable electrical components have different configurations. For instance, an adjustable capacitor or a switch can be connected across a segment of the coil to shunt that segment from the rest of the segments. Alternatively, a switch can be connected in series between one segment and another to disconnect one of the segments from the RF circuitry.

The invention also provides a method of generating a transformer coupled plasma, the method comprising the steps of introducing a process gas into a plasma reaction chamber and resonating a radio frequency current in a coil comprising at least a first coil segment and a second coil segment connected in series and disposed proximate the chamber. The RF current excites the process gas into a plasma within the chamber. The method further comprises a step of varying the radio frequency current in each of the segments to improve the spatial uniformity of RF power coupling in the plasma and in turn improve the plasma and process uniformity such as etching, deposition, etc., in the reaction chamber.

The method is preferably carried out using the various a coil configuration as previously mentioned. Further, the plasma can be used to process one or more substrates such as semiconductor wafers. For instance, the reaction chamber

can be sized to process a single semiconductor wafer at a time and a layer on the wafer can be etched or deposited by the plasma. During processing, the chamber is typically maintained at a wide range of pressures, such as less than 100 mTorr.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a plasma generating device employing a conventional single winding coil;

FIG. 2 is a perspective schematic view in detail of a conventional single winding monolithic coil;

FIG. 3 is a perspective schematic view of a segmented coil configuration according to a first embodiment of the present invention;

FIG. 4 is a perspective schematic view of a segmented coil configuration according to a second embodiment of the present invention;

FIG. 5 is a perspective schematic view of a segmented coil configuration according to a third embodiment of the present invention; and

FIG. 6 is a schematic diagram of a plasma generating device employing a segmented coil according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention relates to plasma processing of substrates, such as semiconductor wafers, flat panel displays, etc. In the case of processing such substrates, it is usually desired to provide a uniform plasma density above the exposed surface of the substrate to be processed. However, depending on the treatment to be performed on the substrate surface, non-uniform plasma density can occur above the surface. For instance, the plasma density may be greater at the substrate center than at the edge thereof or vice versa. The segmented coil of the present invention enable an adjustable RF current to be provided in each of plural segments of the TCP coil and thus achieve substantial improvement in uniformity compared to previously known coil arrangements.

The invention provides a segmented transformer coupled plasma (TCP) coil segment with at least a first coil and a second coil which, when connected to an RF source, efficiently generates a uniform plasma. Since the segmented TCP coil has multiple coil segments, variable electrical components can be connected to the individual coils, allowing RF current in each segment to be changed relative to the other segments. The current in each segment can thus be adjusted to improve the spatial uniformity of RF power deposition in the plasma and to in turn improve the plasma and etching uniformity in the plasma chamber.

FIG. 3 is a schematic drawing of a segmented TCP coil configuration according to a first embodiment of the invention. As shown in FIG. 3, the TCP coil 50 is divided into two concentric coil segments, each including an inner terminal, an outer terminal and at least one arcuate conductor portion extending between the inner and outer terminals. The two concentric coil segments are electrically connected in series with each other and are electrically connected in series to an RF source (not shown). The coil 50 includes a first inner coil segment 52 and a second outer coil segment 54. An inner tap labeled (+), and an outer tap, i.e. terminal, labeled (−) are provided to facilitate connection to the RF circuitry. An adjustable (i.e., variable) capacitor Ci is connected across the first coil 52 segment to reduce or shunt current that would otherwise flow through the first coil. This segmented

coil arrangement allows the plasma uniformity to be varied. This is done by changing the value of Ci, which varies the current through the first coil segment 52, which in turn varies the rate plasma is generated in an area in the plasma chamber beneath the coil segment 52. If the value of Ci is high, the capacitor has a low reactive impedance shunting coil 52, so less r.f. current flows through coil 52 and plasma generation in the area beneath coil 52 is reduced ~~while coil~~ 54 continues to generate substantially the same amount of plasma in the area below the coil 54. Conversely, if the value of Ci is low, the capacitor has a high reactive impedance shunting coil 52, so the r.f. current flowing through coil segment 52 is not appreciably reduced so both coil segments 52,54 generate plasma in the areas below them.

The capacitor Ci is not an active element in impedance matching. Further, the capacitance of the capacitor Ci is not intended to be continually adjusted, but rather, the capacitor Ci is preset to a desired value, depending upon the particular process and uniformity required for the substrate undergoing processing.

A segmented TCP coil according to a second embodiment of the invention is illustrated in FIG. 4. Referring to FIG. 4, instead of shunting the first coil segment 52 with a capacitor Ci, a switch S1 is used to reduce or shunt the current that would otherwise flow through the first coil segment. Using the switch S1, there are two modes of operation. In one mode, the first coil segment 52 and the second coil segment 54 are connected in series when the switch S1 is open and the effects are similar to the FIG. 3 embodiment when the value of Ci is low. In the second mode, the second coil segment 54 is connected in series with a shunted first coil segment 52 when the switch S1 is closed and the effects are similar to the FIG. 3 embodiment when the value of Ci is high.

FIG. 5 is an illustration of a third embodiment of the segmented TCP coil. As shown in FIG. 5, instead of shunting the first coil segment 52, a switch S2 is connected between the second coil segment 54 and the input to the first coil segment 52 to selectively remove the first coil segment 52 from the RF circuitry. Using the switch S2, there are two modes of operation. In the first mode, the first coil segment 52 and the second coil segment 54 are connected in series when the switch S2 is closed and the effects are similar to the FIG. 3 embodiment when the value of Ci is low. In the second mode, the first coil segment 52 is disconnected from the RF circuitry and the second coil segment 54 is connected in series with the RF circuit, when the switch S2 is open, the effect being similar to the FIG. 3 embodiment when the value of Ci is high.

The segmented TCP coil described in the embodiments above permits control of the plasma processing on different parts of the substrate undergoing treatment. For example, in plasma etching process, sufficient reduction of the center etch rate is obtained by reducing the current flowing through the first, i.e. inner coil segment. By controlling the etch rate on different parts of the wafer, a uniformly etched wafer surface can be obtained.

A plasma generating device employing the segmented TCP coil is depicted in FIG. 6. Referring to FIG. 6, the segmented TCP coil 50 includes a first coil segment 52 and a second coil segment 54. A variable electrical component V may, for example, be an adjustable capacitor Ci or a switch S1 connected across the first coil segment 52, as shown in FIGS. 3 and 4, or a switch S2 connected between the first coil segment 52 and the second coil segment 54, as shown in FIG. 5. The segmented coil 50 is powered by a single RF